Chapter 6
Additional Environmental Improvement Opportunities

This chapter of the Cleaner Technologies Substitute Assessment (CTSA) identifies and qualitatively discusses techniques that can be used by printed wiring board (PWB) manufacturing facilities to prevent pollution, minimize waste, recycle and recover valuable resources, and control releases. The Pollution Prevention Act of 1990 set forth the following hierarchy to waste management in order of desirability:

- pollution prevention at the source;
- recycling in an environmentally safe manner;
- treatment in an environmentally safe manner; and
- disposal or other release into the environment only as a last resort and in an environmentally safe manner.

This hierarchy has been adopted by EPA as the preferred method of waste management to reduce or eliminate potential releases by industry. The hierarchy reflects the common sense notion that preventing pollution in an environmentally safe manner is preferable to any subsequent response, be it recycling, treatment, or disposal. Acceptable pollution prevention methods include product and process redesign and the selection of safe substitutes for problem processes/chemicals, along with other traditional pollution prevention techniques that reduce pollution at the source (Kling, 1995).

The hierarchy also recognizes that pollution prevention is not always possible and that other waste management methods are often required. When pollution prevention is not possible, we should turn in order to recycling, treatment, and finally disposal if no other option remains. A manufacturing facility often combines pollution prevention techniques with these other approaches to effectively reduce emissions from a production process. While pollution prevention is generally the most desirable of the above choices, the most important aspect of this hierarchy is to reduce the environmental impacts of the overall process as much as is feasible while maintaining the quality, performance, and safety criteria for the products being manufactured.

This chapter focuses on the application of the waste management hierarchy to waste streams generated by the surface finishing process of the PWB industry. Techniques are identified, organized, and presented in an order corresponding to the hierarchy. Pollution prevention techniques are presented in Section 6.1, while methods for minimizing waste, recycling or recovering resources, and controlling releases are presented in Section 6.2. While the focus of this chapter is on the surface finishing line, many of the techniques described here can be applied to other processes used in PWB manufacturing. A series of pollution prevention case studies developed by the EPA Design for the Environment (DfE) Program for the PWB industry present examples of the successful implementation of techniques available to industry (U.S. EPA, 1995a; U.S. EPA, 1995b; U.S. EPA, 1996a; U.S. EPA, 1996b; U.S. EPA, 1996c; U.S. EPA, 1997a; U.S. EPA, 1997b; U.S. EPA, 1997c; U.S. EPA, 1999).

6.1 POLLUTION PREVENTION

Pollution prevention, defined in the Pollution Prevention Act of 1990, is the reduction in the amounts or hazards of pollution at the source and is often referred to as source reduction. Source reduction, also defined in the Pollution Prevention Act, is any practice which: 1) reduces the amount of any hazardous substance, pollutant, or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment, or disposal; and 2) reduces the hazards to public health and the environment associated with the release of such substances, pollutants, or contaminants. Source reduction/pollution prevention includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, and improvements in housekeeping, maintenance, training, or inventory control.

EPA's regulations are moving towards incorporating pollution prevention options. For example, the EPA Office of Water is currently developing a set of proposed effluent guidelines for the metal products and machinery industries, which are expected to be published in October, 2000. The proposed rule will discuss ten options that can be employed to meet effluent guidelines and standards, five of which include specific pollution prevention technologies.

Current pollution prevention practices within the PWB industry were identified and data were collected through contact with industry personnel, extensive review of published accounts, and through the design and dissemination of two information requests to PWB manufacturers. The PWB Workplace Practices Questionnaire, conducted as part of this CTSA, specifically focused on the surface finishing process to identify important process parameters and operating practices for the various surface finishing technologies. For a breakdown of respondents by alternative, refer to Section 1.3 of the Introduction. Facility characteristics of respondents are presented in Section 3.2, Exposure Assessment. The PWB Workplace Practices Questionnaire is presented in Appendix A.

The Pollution Prevention and Control Technology Survey (hereafter referred to as the Pollution Prevention Survey) was an update to a previous survey and was designed to collect information about past and present pollution prevention procedures and control technologies for the entire PWB manufacturing process. This Survey was performed by the DfE PWB Project and is documented in the EPA publication, *Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Updated Survey Results* (U.S. EPA, 1998). The Survey results presented periodically throughout this chapter are compiled from responses to the Pollution Prevention Survey unless otherwise indicated. Results from the Pollution Prevention Survey pertaining to recycle or control technologies are presented in Section 6.2 of this chapter.

Opportunities for pollution prevention in PWB manufacturing were identified in each of the following areas:

- management and personnel practices;
- materials management and inventory control;
- materials selection; and
- process improvements.

The successful implementation of pollution prevention practices can lead to reductions in waste treatment, pollution control, environmental compliance, and liability costs. Cost savings can result directly from pollution prevention techniques that minimize water usage, primary or ancillary material consumption, and process waste generation.

6.1.1 Management and Personnel Practices

Pollution prevention is an ongoing activity that requires the efforts of both management and employees to achieve the best results. While pollution prevention initiatives, such as an ISO 14000-type environmental management system, require a commitment and continued support from management, any pollution prevention measures taken are ultimately implemented by the process employees, making them an integral part of any pollution prevention effort. Management and employees must work together to form an effective pollution prevention program.

Just under two thirds (60.9 percent) of the PWB companies responding to the Pollution Prevention Survey reported having a formal pollution prevention policy statement while just over half (55.1 percent) of the survey respondents reported having a pollution prevention program. Over two thirds (71.2 percent) of PWB companies surveyed reported conducting employee education for pollution prevention. Each of these statistics in the current Pollution Prevention Survey increased between three and eight percent over the same statistics in the prior survey, showing improvement in company perspectives on pollution prevention since the previous survey was conducted.

The scope and depth of pollution prevention planning and the associated activities will vary with the size of the facility. While larger facilities may go through an entire pollution prevention planning exercise (as described below), smaller facilities may require as little as a commitment by the owner to pollution prevention along with cooperation and assistance from employees to meet any stated goals. A list of management and personnel practices that promote pollution prevention, along with the benefits, are listed in Table 6-1.

A company's commitment to pollution prevention begins with a pollution prevention and waste reduction policy statement. This statement, which is the company's public proclamation of its dedication to preventing pollution and reducing waste, should clearly state why a program is being undertaken, include specific pollution prevention and waste reduction goals, and assign responsibility for accomplishing those goals. The statement details to the public and to its employees the depth of the company's commitment to pollution prevention.

Table 6-1. Management and Personnel Practices Promoting Pollution Prevention

Method	Benefits
Create a company pollution prevention and waste reduction policy statement.	Communicates to employees and states publicly the company commitment to achieving pollution prevention and waste reduction goals.
Develop a written pollution prevention and waste reduction plan.	Communicates to employees how to accomplish the goals identified in the company's policy statement. Identifies in writing specific implementation steps for pollution prevention.
Provide periodic employee training on pollution prevention.	Educates employees on pollution prevention practices.
Make employees accountable for their pollution prevention performance and provide feedback on their performance.	Provides incentives to employees to improve pollution prevention performance.
Promote internal communication between management and employees.	Informs employees and facilitates input on pollution prevention from all levels of the company.
Implement total cost accounting or activity-based accounting system.	Identifies true costs of waste generation and the benefits of pollution prevention.

A pollution prevention plan is needed to detail how the pollution prevention and waste reduction goals described in the company's policy statement will be achieved. The pollution prevention plan builds on the company's policy statement by:

- creating a list of waste streams and their point sources;
- identifying opportunities for pollution prevention;
- evaluating and prioritizing waste reduction options;
- developing an implementation strategy for options that are feasible;
- creating a timetable for pollution prevention implementation; and
- detailing a plan for measuring and evaluating pollution prevention and waste reduction progress.

The plan is best developed with input drawn from the experiences of a team of people selected from levels throughout the company. The team approach provides a variety of perspectives to pollution prevention and helps to identify pollution prevention opportunities and methods for implementing them. Team members should include representatives from management, supervisory personnel, and line workers who are familiar with the details of the daily operation of the process. The direct participation of line workers in the development of the pollution prevention plan is important since it is the employees who are responsible for implementing the plan.

Data should be collected by performing an assessment of the process(es) being targeted. It is not possible to develop a pollution prevention plan unless there exists good data on the rate at which primary and ancillary materials are used and wastes are generated. Once the assessment and data collection are complete, pollution prevention options should be evaluated and prioritized based on their cost, feasibility of implementation, and their overall effectiveness of eliminating or reducing waste. After an implementation strategy and timetable is established, the plan, along with expected benefits, should be presented to the remaining company employees to communicate the company's commitment to pollution prevention.

Once the pollution prevention plan has been finalized and implementation is ready to begin, employees must be given the skills to implement the plan. Training programs play an important role in educating process employees about current pollution prevention practices and opportunities. The goal of the training program is to educate each employee on how waste is generated, its effects on worker safety and the environment, possible methods for waste reduction, and on the overall benefits of pollution prevention.

Employee training should begin at the time of new employee orientation, introducing them to the company's pollution prevention plan, thus highlighting the company's dedication to reducing waste. More advanced training focusing on process operating procedures, potential sources of release, and pollution prevention practices already in place should be provided after a few weeks of work or when an employee starts a new position. Retraining employees periodically will keep them focused on the company's goal of pollution prevention.

Effective communication between management and employees is an important part of a successful pollution prevention program. Reports to employees on the progress of implementing pollution prevention recommendations, as well as the results of actions already taken, reiterate management's commitment to reducing waste, while keeping employees informed and intimately involved in the process. Employee input should also be solicited both during and after the creation of the pollution prevention plan to determine if any changes in the plan are warranted.

Assigning responsibility for each source of waste is an important step in closing the pollution prevention loop. Making individual employees and management accountable for chemical usage and waste generated within their process or department provides incentive for employees to reduce waste. The quantity of waste generated should be tracked and the results reported to employees who are accountable for the process generating the waste. Progress in pollution prevention should be an objective upon which employees will be evaluated during performance reviews, once again emphasizing the company's commitment to waste reduction.

Employee initiative and good performance in pollution prevention areas should be recognized and rewarded. Employee suggestions that prove feasible and cost effective should be implemented and the employee recognized either with a company commendation or with some kind of material award. These actions will ensure continued employee participation in the company's pollution prevention efforts.

Implementing an activity-based or total cost accounting system will identify the costs of waste generation that are typically hidden in overhead costs by standard accounting systems. These cost accounting methods identify cost drivers (activities) within the manufacturing process and assign the costs incurred through the operation of the process to the cost drivers. By identifying the cost drivers, manufacturers can correctly assess the true cost of waste generation and the benefits of any pollution prevention efforts.

The International Standards Organization has developed the ISO 14001 standard which defines specific Environmental Management System (EMS) criteria for certification by the organization. Although the standard has been recently established, many companies are already seeking certification to demonstrate their commitment to environmental performance. More information on the ISO environmental standards can be found at the ISO's website: <http://www.iso.ch/welcome.html>.

An alternative to the ISO 14001 model for EMS is the DfE EMS. It is based on the structure outlined in the ISO 14001 standard and incorporates the five phases of Commitment, Policy, Planning, Implementation, Evaluation and Review. While generally consistent with the ISO 14001 standard, the DfE EMS places less emphasis on management infrastructure and documentation and more emphasis on pollution prevention and risk reduction. The DfE EMS is designed for small- and medium-sized businesses and provides technical guidance and detailed methods for developing an EMS. The DfE EMS allows a company to create a simple yet effective EMS aimed at improving environmental performance by focusing on substitutes assessments, chemical risk reduction, pollution prevention opportunities, and resource and cost savings. DfE has developed an EMS guidance manual and several assessment tools that are available on the DfE EMS website: <http://www.epa.gov/opptintr/dfe/tools/ems/ems.html>.

6.1.2 Materials Management and Inventory Control

Materials management and inventory control focuses on how chemicals and materials flow through a facility in order to identify opportunities for pollution prevention. A proper materials management and inventory control program is a simple, cost effective approach to preventing pollution. Table 6-2 presents materials management and inventory control methods that can be used to prevent pollution.

Table 6-2. Materials Management and Inventory Control Pollution Prevention Practices

Practice	Benefits
Minimize the amount of chemicals kept on the floor at one time.	Provides incentives to employees to use less chemicals.
Manage inventory on a first-in, first-out basis.	Reduces materials and disposal costs of expired chemicals.
Return unused chemicals to inventory.	Reduces chemical and disposal costs.
Centralize responsibility for storing and distributing chemicals.	Provides incentives to employees to use less chemicals.
Store chemical products in closed, clearly marked containers.	Reduces materials loss; increases worker safety by reducing worker exposure.
Use a pump to transfer chemical products from stock to transportation container.	Reduces potential for accidental spills; reduces worker exposure.

Controlling inventory levels and limiting access to inventory are widely used practices in the PWB manufacturing industry (82.7 percent of Pollution Prevention Survey respondents). Keeping track of chemical usage and limiting the amount of chemicals on the process floor provides process operators an incentive to use the minimum quantity of chemical required to do the job. Using chemicals on a first-in/first-out basis reduces the time chemicals spend in storage and the amount of expired chemicals that are disposed. Some companies have contracted with a specific chemical supplier to provide all of their process chemicals and manage their inventory. In exchange for the exclusive contract, the chemical supplier assumes many of the inventory management duties including managing the inventory, material safety data sheets (MSDSs), ordering the chemicals, distributing the chemicals throughout the plant, and disposing of spent chemicals and packaging (Brooman, 1996).

Chemical storage and handling practices also provide pollution prevention opportunities. Ensuring that all chemical containers are kept closed when not in use minimizes the amount of chemical lost through evaporation or volatilization. When transferring chemicals from container to container, utilizing a hand pump can reduce the amount of chemical spillage. These simple techniques not only result in less chemical usage representing a cost savings, but also result in reduced worker exposure and an improved worker environment.

6.1.3 Material Selection

Often times, decreasing the amount of pollution a particular process generates can be as simple as selecting different materials for use in the process. This could include primary materials such as bath chemicals or ancillary materials such as racks or rack coverings, and is dependent upon the availability of alternatives to the currently chosen material.

For example, the selection of the proper flux can greatly reduce the air emissions from the hot air solder leveling (HASL) process. In the HASL process, the boards are immersed in a bath of flux followed by submersion in a bath of solder mixed with oil. A hot air knife is then utilized to remove excess solder and oil from the board. An air emission is created during these steps that is the result of the bath chemicals being heated to fairly high temperatures (e.g., 450°F for the oil and solder mixture) and both the oil and flux having vapor pressures that when heated encourage a portion to evaporate and condense as fine droplets (Lee, 1999).

Most flux manufacturers fabricate multiple types of flux for use in the many different environments that exist in PWB manufacturing, some producing as many as 30 to 40 different fluxes. Each flux is manufactured to work most effectively in a particular environment (e.g., low viscosity, high acidity). Carefully choosing the right flux for a particular PWB application can reduce flux losses, the subsequent emissions generated, and the associated costs.

Another example would include choosing the most appropriate type of racking system surface material. With several different types of racking system materials available (e.g., aluminum, iron, stainless steel, plastic, rubber-coated), the unnecessary build-up of bath chemicals on the racks can be reduced. For instance, the use of plastic racks can prevent the deposition of metal on the racks in plating baths, eliminating the need to strip them, thereby reducing the amount of time, effort, and cost that goes into rack cleaning.

6.1.4 Process Improvements

Improving the efficiency of a production process can significantly reduce waste generation at the source. Process improvements include process or procedural changes in operations carried out by employees, process equipment modification or automation, and redesign of the process altogether. Process improvements that lead to pollution prevention in surface finishing are categorized by the following goals:

- extend chemical bath life;
- reduce air emissions;
- reduce water consumption;
- improve process efficiency through automation; and
- segregate waste streams to reduce sludge generation.

Pollution prevention through process improvement does not always have to be expensive. In fact, some of the most cost effective pollution prevention techniques are simple, inexpensive changes in production procedures. Process improvements that help achieve the goals listed above, along with their benefits, are discussed in detail in the sections below.

Extend Chemical Bath Life

The surface finishing process involves the extensive use of chemicals, many of which are costly and pose a hazard to human health and the environment. Improvements in the efficient usage of these chemicals can occur by accomplishing the following:

- reducing chemical bath contamination;
- reducing chemical bath drag-out; and
- improving bath maintenance.

Inefficiencies in the use of chemicals can result in increased chemical usage, higher operating costs, increased releases to the environment, and increased worker exposure. Techniques to improve the efficient use of chemicals by the surface finishing and other PWB process steps are discussed in detail below.

Reduce Bath Contaminants. The introduction of contaminants to a chemical bath will affect its performance and significantly shorten the life of the chemical bath. Bath contaminants include chemicals dragged in from previous chemical baths, chemical reaction by-products, and particulate matter which may be introduced to the bath from the air. Process baths are replaced when impurities reach a level where they degrade product quality to an unacceptable level. Any measure that prevents the introduction of impurities will not only result in better bath performance, but also will reduce chemical usage and generate less waste. Table 6-3 presents pollution prevention methods for reducing bath contamination.

Table 6-3. Pollution Prevention Practices to Reduce Bath Contaminants

Practices	Benefits
Improve the efficiency of the water rinse system.	Rinses off any residual bath chemistries and dislodges any particulate matter from panels and racks.
Use distilled or deionized water during chemical bath make-up.	Reduces chemical contamination resulting from water impurities.
Maintain and rebuild panel racks.	Prevents the build-up of deposits and corrosion that can dislodge or dissolve into chemical baths.
Clean process tanks efficiently before new bath make-up.	Prevents contamination of the new bath from residual spent bath chemistries.
Utilize chemical bath covers when process baths are not in operation.	Reduces the introduction of unwanted airborne particulate matter; prevents evaporation or volatilization of bath chemistries.
Remove immediately foreign objects that have fallen into chemical tank.	Prevents the contamination and premature degradation of bath chemicals.
Filter contaminants continuously from process baths.	Prevents the build-up of any contaminants.

Thorough and efficient water rinsing of process panels and the racks that carry them is crucial to preventing harmful chemical drag-in and to prolonging the life span of the chemical baths. The results of the PWB Workplace Practices Questionnaire indicate that nearly every chemical bath in the surface finishing process is preceded by at least one water rinse tank. Improved rinsing can be achieved by using spray rinses, panel and/or water agitation, warm water, or by several other methods that do not require the use of a greater volume of water. A more detailed discussion of these methods is presented in the reduced water consumption portion in this section.

A rack maintenance program is also an important part of reducing chemical bath contamination and is practiced by 87 percent of the respondents to the Pollution Prevention Survey. By cleaning panel racks regularly and replacing corroded metal parts, preferably with parts of plastic or stainless steel, chemical deposition and build-up can be minimized. Respondents to the PWB Workplace Practices Questionnaire typically perform rack cleaning using either a chemical process that is either part of the process or a separate acid bath, or a mechanical method. Mechanical methods, such as peeling or filing away the majority of any metal deposits before applying a weak acid solution, can be used to prevent pollution by reducing the quantity of acid required. An added benefit is that the reclaimed metal can be sold or reused in the process.

According to the PWB Workplace Practices Questionnaire, 42 percent of the respondents reported using bath covers on at least some of their baths during periods when the surface finishing process was not operating. Respondents were not specifically questioned about the other methods for reducing bath contamination described above; consequently, no information was collected.

Chemical Bath Drag-Out Reduction. The primary loss of bath chemicals during the operation of the surface finishing process comes from chemical bath drag-out. This loss occurs as the rack full of panels is being removed from the bath, dragging with it a film of chemical solution still coating the panels. The drag-out is then either removed from the panels by a hot air knifing process, which uses air to remove excess chemical solution retained on the boards, or is simply carried into the next bath. In most cases, the panels are deposited directly into the next process bath without first being air knifed.

As an extension of the making holes conductive and surface finishing DfE projects, a mathematical tool was developed to help predict the volume of bath chemistry lost through panel drag-out. The model identifies multiple process parameters (e.g., number of through holes, size of panel, length of drip time, etc.) and bath characteristics (e.g., bath temperature, viscosity, etc.) that directly affect the volume of drag-out. Process data for the model were obtained from the PWB Workplace Practices Questionnaire and from data provided by individual chemical suppliers. Because the primary daily loss of bath chemistry is through drag-out, using the model to minimize drag-out will result in extended bath life, decreases in rinse water and bath chemistry usage, and a reduction in treatment sludge. The drag-out model along with a complete description of the method of development, individual factors in the model, and the model limitations is presented in Appendix E. Drag-out model results for the surface finishing alternatives are presented in Section 3.2, Exposure Assessment.

Techniques that minimize bath drag-out also prevent the premature reduction of bath chemical concentration, extending the useful life of a bath. In addition to extended bath life, minimizing or recovering drag-out losses also has the following effects:

- minimizes bath chemical usage;
- reduces the quantity of rinse water used;
- reduces chemical waste;
- requires less water treatment chemical usage; and
- reduces overall process cost.

Methods for reducing or recovering chemical bath drag-out are presented in Table 6-4 and discussed below.

The two most common methods of drag-out control employed by respondents to the Pollution Prevention Survey that require no capital investment are increased panel drainage time (76.3 percent) and practicing slow rack withdrawal from process tanks (60.5 percent). Increasing the time allowed for the panels to drain over the process bath allows a greater percentage of potentially removable chemicals to remain in the bath. Practicing slow rack withdrawal during rack removal is another step used relatively often to allow more time for the bath chemicals to drip back into the bath. Neither of these techniques requires capital investment and both are effective methods for reducing drag-out.

Another viable option is to use drip shields, which are plastic panels that extend the wall height of the process tank. Drip shields are inexpensive, effective drag-out control options, and require no space between process steps, making them very practical where process space is an issue.

Much of the chemical solution lost to drag-out can be recovered through the use of either static drag-out tanks or drip tanks. A static drag-out tank is a batch water bath that immediately follows the process bath from which the drag-out occurs. The panels are submerged and agitated in the static rinse water, washing the residual chemicals from the panel's surface. When sufficiently concentrated, the rinse water and chemical mixture can be used to replenish the original bath. Drip tanks are similar to static drag-out tanks except that they contain no water. The drip tank collects chemical drag-out which can then be returned to the process bath. Static drag-out tanks are most suitably used in conjunction with heated process baths which lose water by evaporation, requiring frequent replacement.

Table 6-4. Methods for Reducing Chemical Bath Drag-Out

Methods	Benefits
Remove panels slowly from process baths.	Reduces the quantity of residual chemical on panel surfaces.
Increase panel drainage time over process bath.	Allows a greater volume of residual bath chemistries to drip from the panel back into the process bath.
Agitate panels briefly while draining.	Dislodges trapped bath chemistries from drilled through holes.
Install drain boards.	Collects and returns drag-out to process baths.
Install drip shields between process baths.	Prevents bath chemical loss due to splashing.
Add static drag-out tanks/drip tanks to process line where needed.	Recovers chemical drag-out for use in bath replenishment.
Utilize non-ionic wetting agents in the process bath chemistries.	Reduces surface tension of bath solutions, thereby reducing residual chemicals on panel surfaces.
Utilize air knives directly after process bath in conveyorized system. [a]	Blows residual process chemistries from process panels which are recaptured and returned to process bath.
Employ fog rinses/spray rinses over heated baths. [a]	Rinses drag-out from the panels as they are removed from the solution.

[a] May not be a viable pollution prevention technique unless system is fully enclosed to prevent worker exposure to bath chemicals introduced to the air.

Bath Maintenance Improvements. The surface finishing processes and other wet chemistry processes in PWB manufacturing consist of a complex, carefully balanced series of formulated chemical mixtures, each one designed to operate at specific conditions, working together to perform an overall function. A bath testing and control program is essential in preventing the chemical breakdown of process baths, thus extending their useful lives and preventing their premature disposal. The premature disposal of process chemistries results in increased chemical costs for both bath and treatment chemicals, prolonged process down-time, and increased process waste.

Bath maintenance, or control, refers to maintaining a process bath in peak operating condition by identifying and controlling key operating parameters, such as bath temperature, individual chemical concentrations, pH, and the concentration of contaminants. Proper control of bath operating parameters will result in more consistent bath operation, less water usage, and better, more consistent quality of work.

According to Pollution Prevention Survey respondents, the majority of PWB manufacturing facilities (72.4 percent) have a preventative bath maintenance program already in place. Typical bath maintenance methods and their benefits are presented in Table 6-5 below.

Table 6-5. Bath Maintenance Improvement Methods To Extend Bath Life

Methods	Benefits
Monitor bath chemistries by testing frequently.	Determines if process bath is operating within recommended parameters.
Replace process baths according to chemical testing.	Prevents premature chemical bath replacement of good process baths.
Maintain operating chemical balance through chemical additions according to testing.	Maintains recommended chemical concentrations through periodic chemical replenishment as required.
Filter process baths continuously.	Prevents the build-up of harmful impurities that may shorten bath life.
Employ steady state technologies.	Maintains steady state operating conditions by filtering precipitates or regenerating bath solutions continuously.
Install automated/statistical process control system.	Provides detailed analytical data of process operating parameters, facilitating more efficient process operation.
Utilize temperature control devices.	Regulates bath temperatures to maintain optimum operating conditions.
Utilize bath covers.	Reduces process bath losses to evaporation and volatilization.

Frequent monitoring and adjustment of the various chemical concentrations within a process bath are the foundations on which a good bath maintenance program is built. Monitoring is done by regularly testing the bath concentrations of key chemicals to ensure that the bath is chemically balanced. If chemical concentrations are outside of the operating levels recommended by the supplier, a volume of chemical is added to the bath to bring it back into balance. When the concentration of contaminants reaches an established critical level, or some other criterion provided by the supplier, the bath is disposed of and replaced with a new bath.

Bath testing and adjustment can be performed manually or with an automated system that can perform both functions. Either way, controlling the bath through regular testing and bath additions is an inexpensive, effective method for extending bath life and reducing pollution. Nearly all of the PWB facilities surveyed (93.1 percent) reported testing chemical bath concentrations, adding chemicals as necessary and maintaining records of the analysis and additions.

Bath replacement should be based upon chemical testing, instead of some other predetermined criteria. Predetermined criteria, such as times or production volumes, are often given by suppliers as safe guidelines for bath replacement for facilities that do not regularly test their process baths. These criteria are conservative estimates of the effective life of the process bath, but possibly could be exceeded with a proper bath testing and maintenance program. By replacing the process bath only when chemical testing indicates it is required, bath life can be extended while chemical usage and waste are reduced. Most (95.0 percent) of the surveyed PWB facilities reported replacing their process baths only when testing indicated.

The build-up of contaminants in a process bath will eventually require the bath to be replaced. Bath contaminants can be solid matter, such as particulate matter and precipitates, or undesired chemical species in solution, such as reaction by-products or drag-in chemicals. Installing standard cartridge or bag filters to continuously remove solid impurities from the bath is an inexpensive, yet effective method to extend bath life.

Additionally, some baths may be maintained at steady state conditions using readily obtainable systems capable of regenerating or filtering process bath chemistries. Although these systems may require capital investment, maintaining steady state conditions keeps a bath within the optimal operating conditions resulting in extended bath life and increased cost savings (Edwards, 1996).

Statistical process control (SPC) is a method of analyzing the current and past performance of a process bath, using chemical testing results and operating condition records to optimize future bath performance. SPC will lead to more efficient bath operation and extended bath life by indicating when a bath needs maintenance through the tracking and analysis of individual operating parameters and their effect on past performance (Fehrer, 1996).

A method of limiting evaporative losses from process baths is to cover the surface of the solution with floating plastic balls that will not react with the process solution. The plastic balls, similar to ping pong balls which do not interfere with the work pieces being processed, prevent the evaporation of the bath solution by limiting the surface area of solution exposed to the air. Hexagonal shaped balls are now available that leave even less surface area exposed to the air (Brooman, 1996). This method is especially effective for higher temperature process baths where evaporative losses tend to be high. This method is inexpensive, easy to utilize, and will decrease the air emissions from the bath, limiting the amount of operator exposure to the chemicals.

Reduce Air Emissions

During surface finishing, air emissions are generated from some chemical baths. When the chemicals being used pose a hazard to human health, hoods are utilized to collect the emissions and move them away from the workers. These emissions are ducted to air emission control devices as necessary. These emissions increase the costs associated with PWB manufacture, thus efforts that reduce these emissions not only produce cost savings but reduce worker exposure and reduce the environmental impacts of the process.

One particularly troublesome source of air emissions during the HASL process is the application of a flux and a subsequent solder to the PWB, which generates air emissions that can include oil mist, oxides of lead and tin, hydrogen chloride or hydrogen bromide, and copper chloride or copper bromide (chlorine or bromine is typically used as the flux activator). This process typically requires pollution control equipment like a wet scrubber followed by a diffusion-type fiber bed filter, to control not only the pollutants but also the odors created by their release.

The most prominent option available to reduce these HASL process air emissions comes in the form of process redesign, or utilizing an alternative surface finishing (ASF) technology. Although most of the ASF technologies being evaluated in this CTSA also have air emissions of one type or another, it is the current understanding that one or more will offer a reduction in the overall quantity and/or toxicity of the air emissions generated while maintaining product quality and performance criteria. Depending on the characteristics of the particular boards needing surface finishing (e.g., their aspect ratio), an ASF technology might provide performance either similar to or better than the HASL process while reducing the surface finishing process' environmental impacts.

Reduced Water Consumption

Contaminated rinse water is one of the primary sources of heavy metal ions discharged to waste treatment processes from the surface finishing process and other wet chemistry process lines (Bayes, 1996). These contaminants, which are introduced to the rinse water through chemical drag-out, must be treated and removed from the water before it can be reused in the process or discharged to the sewer. Because rinsing is often an uncontrolled portion of the process, large quantities of water are consumed and treated unnecessarily. Reducing the amount of water used by the surface finishing process has the following benefits:

- decreases water and sewage costs;
- reduces wastewater treatment requirements, resulting in less treatment chemical usage and reduced operating costs;
- reduces the volume of sludge generated from wastewater treatment, which results in reduced sludge treatment or disposal costs; and
- improves opportunities to recover process chemicals from more concentrated waste streams.

The surface finishing process line consists of a series of chemical baths, which are typically separated by at least one, and sometimes more, water rinse steps. These water rinse steps account for virtually all of the water used during the operation of the surface finishing line. The water baths act as a buffer, dissolving or displacing any residual drag-in chemicals from the panel surface. The rinse baths prevent contamination of subsequent baths while creating a clean surface for future chemical activity.

Improper rinsing not only leads to shortened bath life through increased drag-in, as discussed previously, but can also lead to a host of problems affecting product quality, such as peeling, blistering, and staining. Insufficient rinsing of panels can lead to increased chemical drag-in quantities and will fail to provide a clean panel surface for subsequent chemical activity. Excessive water rinsing, done by exposing the panels too long to water rinsing, can lead to oxidation of the copper surface and may result in peeling, blistering, and staining. To avoid insufficient rinsing, manufacturers often use greater water flow rates than are necessary, instead of using more efficient rinsing methods that reduce water consumption but may be more expensive to implement. These practices were found to be true among survey respondents, where facilities with low water and sewage costs typically used much larger amounts of water than comparable facilities with high water and sewer costs.

Many techniques are available that can reduce the amount of water consumed while rinsing. These techniques are categorized by the following:

- methods to control water flow;
- techniques to improve water rinse efficiency; and
- good housekeeping practices.

Flow control methods focus on controlling the flow of water, either by limiting the maximum rate that water is allowed to flow into the rinse system, or by stopping and starting the water flow as it is needed. These methods seek to limit the total water usage while ensuring that sufficient water is made available to cleanse the PWB panels. Examples of these techniques include the use of flow restrictors or smaller diameter piping to limit the maximum flow of water, and control valves that provide water to the rinse baths only when it is needed. Control valves can be either manually operated by an employee, or automated using some kind of sensing device such as conductivity meters, pH meters, or parts sensors. All of the methods are effective water reduction techniques that can be easily installed.

Pollution prevention techniques directed at improving water efficiency in the rinse system seek to control or influence the physical interaction between the water and the panels. This can be done by increasing bath turbulence, improving water quality, or by using a more efficient rinse configuration. All of these methods, discussed below, seek to improve rinsing performance while using less water.

Increasing bath turbulence can be accomplished through the use of ultrasonics, panel agitation, eductors (nozzles below the surface that circulate solution), or air sparging. All of these agitation methods create turbulence in the bath, increasing contact between the water and the part, thereby accelerating the rate that residual chemicals are removed from the surface. Agitating the bath also keeps the water volume well mixed, distributing contaminants throughout the bath and preventing concentrations of contaminants from becoming trapped. However, agitating the bath can also increase air emissions from the bath unless pollution prevention measures are used to reduce air losses.

Water quality can be improved by using distilled or deionized water for rinsing instead of tap water that may include impurities such as carbonate and phosphate precipitates, calcium, fluoride, and iron. Finally, utilizing more efficient rinse configurations such as countercurrent rinse stages, spray rinses, or fog rinses will increase the overall efficiency of the surface finishing rinse system while reducing the volume of wastewater generated. PWB manufacturers often use multiple rinse water stages between chemical process steps to facilitate better rinsing. The first rinse stage removes the majority of residual chemicals and contaminants, while subsequent rinse stages remove any remaining chemicals. Counter-current or cascade rinse systems minimize water use by feeding the water effluent from the cleanest rinse tank, usually at the end of the cascade, into the next cleanest rinse stage, and so on, until the effluent from the most contaminated, initial rinse stage is sent for treatment or recycle.

Good housekeeping practices focus on keeping the process equipment in good repair and fixing or replacing leaky pipes, pumps, and hoses. These practices can also include installing devices such as spring loaded hose nozzles that shut off when not in use, or water control timers that shut off water flow in case of employee error. These practices often require little investment and are effective in preventing unnecessary water usage. For a more detailed discussion on methods of improving water rinse efficiency and reducing water consumption, refer to Section 5.1, Resource Conservation.

Improve Process Efficiency Through Automation

The operation of the surface finishing process presents several opportunities for important and integral portions of the process to become automated. By automating important functions, operator inconsistencies can be eliminated, allowing the process to be operated more efficiently. Automation can lead to the prevention of pollution by:

- gaining a greater control of process operating parameters;
- performing the automated function more consistently and efficiently;
- eliminating operator errors; and
- making the process compatible with newer and cleaner processes designed to be operated with an automated system.

Automating a part of the surface finishing process can be expensive. The purchase of some automated equipment can require a significant initial investment, which may prevent small companies from automating. Other costs that may be incurred include those associated with installing the equipment, training employees, any lost production due to process down-time, and redesigning other processes to be compatible with the new system. Although it may be expensive, the benefits of automation on productivity and waste reduction will result in a more efficient process that can save money over the long run.

Installation of automated equipment such as a rack or panel transportation system, chemical sampling equipment, or an automated system to make chemical additions can have a major impact on the quantity of pollution generated during the day-to-day operation of the surface finishing process and can also reduce worker exposure. Surface finishing process steps or functions that can be automated effectively include:

- rack transportation;
- bath maintenance; and
- water flow control.

Rack transportation systems present an excellent opportunity for automation, due to the repetitive nature of transporting panel racks. Various levels of automation are available ranging from a manually operated vertical hoist to a computer controlled robotic arm. All of these methods allow for greater process control over panel movement through the surface finishing process line. By building in drag-out reduction methods such as slower panel withdrawl and extended drainage times into the panel movement system, bath chemical loss and water contamination can be greatly reduced.

Automating bath maintenance testing and chemical additions can result in longer bath life and reduced waste. These systems monitor bath solutions by regularly testing bath chemistries for key contaminants and concentrations. The system then adjusts the process bath by making small chemical additions, as needed, to keep contaminant build-up to a minimum and the process bath operating as directed. The resulting process bath operates more efficiently, resulting in prolonged bath life, less chemical waste, reduced chemical cost, and reduced drag-out.

Controlling rinse water flow is an inexpensive process function to automate. Techniques for controlling rinse water flow were discussed previously. The reduction in fresh water usage as a result of automating these techniques will not only reduce water costs, but will also result in reduced treatment chemical usage and less sludge.

A conveyorized system integrates many of the methods described above into a complete automated surface finishing system. The system utilizes a series of process stages connected by a horizontal conveyor to transport the PWB panels through the surface finishing process. Drag-out is greatly reduced due, in part, to the separate process stages, and to the vertical alignment of the drilled holes that trap less chemicals. Since drag-out is reduced, much less rinse water is required to cleanse the panel surfaces, resulting in reduced water and treatment costs. A single water tank is sufficient between process baths, whereas multiple stages may be required in a non-conveyorized process. Thus, automation dramatically reduces the number of process stages required, resulting in a much shorter cycle time and reduced floor space requirements. The enclosed process stages limit evaporative losses, reducing chemical costs, while also reducing the amount of chemical to which an employee is exposed. Several surface finishing alternative chemistry processes have been designed to operate effectively using this type of conveyorized system.

A conveyorized system should also take advantage of other pollution prevention techniques, such as water flow controllers, bath maintenance techniques and other methods discussed throughout this module, to further reduce waste. By integrating all of these methods together into a single surface finishing system, the process operates more efficiently, reducing water and chemical consumption, resulting in less process waste and employee exposure.

Segregate Wastewater Streams to Reduce Sludge Generation

The segregation of wastewater streams is a simple and cost effective pollution prevention technique for the surface finishing process. In a typical PWB facility, wastewater streams from different process steps are often combined and then treated by an on-site wastewater treatment process to comply with local discharge limits.

Some waste streams from the surface finishing process, however, may contain chelating agents. These chelators, which permit metal ions to remain dissolved in solution at high pH levels, must first be broken down chemically before the waste stream can be treated and the heavy metal ions removed. Treatment of waste containing chelators requires extra treatment steps or more active chemicals to break down the chelating agents and precipitate out the heavy metal ions from the remaining water effluent. Because the chelator-bearing streams are combined with other non-chelated streams before being treated, a larger volume of waste must be treated for chelators than is necessary, which also results in a larger volume of sludge.

To minimize the amount of treatment chemical used and sludge produced, the chelated waste streams should be segregated from the other non-chelated wastes and collected in a storage tank. When enough waste has been collected, the chelated wastes should be batch treated to breakdown the chelator and remove the heavy metals. The non-chelated waste streams can then be treated by the on-site wastewater treatment facility without additional consideration. By segregating and batch treating the chelated heavy metal wastes from other non-hazardous waste streams, the volume of waste undergoing additional treatment is minimized and treatment chemical usage and sludge generation reduced.

6.2 RECYCLE, RECOVERY, AND CONTROL TECHNOLOGIES ASSESSMENT

While pollution prevention is the preferred method of waste management, the pollution prevention hierarchy recognizes that pollution prevention is not always practical. Companies often supplement their pollution prevention efforts with additional waste management techniques to further reduce emissions. These techniques, presented in order of preference, include recycling or reclamation, treatment, and disposal. Techniques for pollution prevention are presented in Section 6.1. This section presents waste management techniques typically used by the PWB industry to recycle or recover valuable process resources (Section 6.2.1), and to control emissions to water and air (Section 6.2.2) from the surface finishing process. Typical treatment configurations presented in this section were developed and reviewed by PWB manufacturers participating in this project.

6.2.1 Recycle and Resource Recovery Opportunities

PWB manufacturers have begun to re-emphasize recycle and recovery technologies, due to more stringent pretreatment effluent limits. Recycling or reclamation is the recovery of process material effluent, either on-site or off-site, which would otherwise become a solid waste, air emission, or would be discharged to a wastewater stream. Technologies that recycle water from waste streams concentrate the final effluent, making subsequent treatment more efficient, which reduces the volume of waste generated and lowers overall water and sewer costs. As a result, these technologies are being used more frequently by industry to recycle or recover valuable process resources, while also minimizing the volume of waste that is sent to disposal. This trend was supported by the respondents of the *Printed Wiring Board Pollution Prevention and Control Technology: Analysis of Updated Survey Results* (U.S. EPA, 1998), 81 percent of whom reported using some type of recycle or resource recovery technology.

Recycle and resource recovery technologies include those that recover materials from waste streams before disposal, or recycle waste streams for reuse in another process. Opportunities for both types of technologies exist within a surface finishing process. Rinse water can be recycled and reused in further rinsing operations, while valuable metals such as copper, silver, palladium, and gold can be recovered from waste streams before disposal and sold to a metals reclaimer. These recycle and recovery technologies may be either in-line (dedicated and built into the process flow of a specific process line) or at-line (employed at the line as desired, as well as at other places in the plant), depending on what is required (Brooman, 1996). Each waste stream that cannot be prevented should be evaluated to determine its potential for effective recycle or resource recovery as part of a pollution prevention and waste management plan.

The decision of whether to purchase a recycle or resource recovery process should be based on several factors. Economic factors, such as process operating and effluent disposal costs for the current system, must be compared with those estimated for the new technology. The initial capital investment of the new technology, along with any potential cost savings, and the length of the payback period must also be considered. Other factors such as the characteristics of the waste stream(s) considered for treatment, the ability of the process to accept reused or recycled materials, and the effects of the recycle or recovery technology on the overall waste treatment process also should be considered.

The entire PWB manufacturing process must be considered when assessing the economic feasibility of a recycle or resource recovery process. An individual recovery process can recover metal from a single stream originating from a surface finishing process, or it may recover the metal from streams that originate from other processes, as well. Only by considering the new technology's impact on the entire PWB manufacturing process can an accurate and informed decision be made. While this section focuses on technologies that may be used to recycle or recover resources from the waste streams that are generated by the surface finishing processes, many of these technologies are also applicable to other PWB process lines. Workplace practices that can lead to the recycle or reuse of resources (e.g., manually recovering copper from panel racks, water recycle using cascade water rinse systems) are discussed in Section 6.1.

Solder Recycling

The application of solder to the surface of PWBs by HASL has been the industry standard finish for many years. The process has long been considered to provide a reliable finish which facilitates assembly and introduces few defects. However, as the concentration of impurities in the solder increases to above 0.3 percent by weight, the quality and appearance of the applied solder finish deteriorates. The solder begins to appear grainy and takes on a dull gray color.

The primary impurity is copper, which is introduced to the molten solder as a by-product of the process reaction. Tin from the molten solder is exchanged with the copper ions on the surface of the exposed copper pads, forming a tin-copper intermetallic layer upon which the solder can adhere. The displaced copper ions remain in the molten solder as a contaminant where they build in concentration until the contamination begins to affect the quality of the solder deposit.

To restore the HASL process to optimum operating conditions, the solder pots typically are refreshed to reduce the contaminant concentration. This maintenance process is performed with the solder in molten form by discarding a substantial quantity of the contaminated solder and replacing it with fresh solder. The contaminated solder (a.k.a. solder dross) can be returned to a recycler to be reclaimed for credit. The effectiveness of the dilution is dependent on the amount of solder replaced, with a 40 percent by weight replacement of solder resulting in roughly a 33 percent decrease in copper contamination, dropping the concentration from 0.3 to 0.2 percent copper. This process is repeated as required to maintain operation of the HASL process (Fellman, 1997).

Solder skimming is another method of purifying the solder. The solder is cooled to a temperature just above the melting point (360 ºF), causing the copper impurities to become insoluble. The copper-tin needles which form are then skimmed from the surface of the solder and handled as waste. Because only the impurities are removed, along with a minimal amount of solder, the skimming process results in much less solder usage over time. However, this method requires open access to the molten solder pot to perform the skimming, so it is typically only associated with some vertical, non-conveyorized HASL machines.

A solder saver, or solder reclaim system, will purify the solder in HASL machines where access to the solder is restricted by air knives, rollers, pumps, or some other equipment, such as in some vertical HASL machines and nearly all horizontal, conveyorized HASL machines. A solder reclaim system diagram is shown in Figure 6-1. The solder saver continuously siphons a portion of the molten solder from the HASL machine to a separate solder pot, where the temperature is lowered and the impurities are skimmed from the solder.

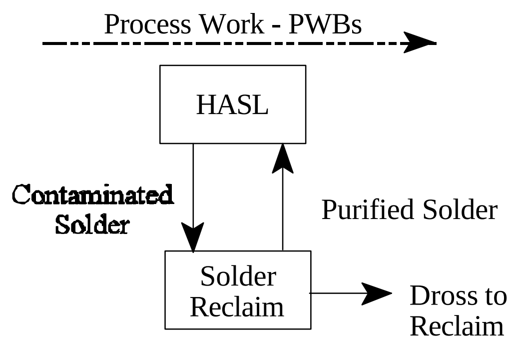

Figure 6-1. Solder Reclaim System Diagram

Impurities that have been skimmed from the solder are collected in a compartment of the machine for removal and disposal, and an equal weight of fresh solder is manually added to maintain operating solder levels. Transfer of the solder from the pot takes place in a heated pipe to prevent the solder from solidifying during the transfer process. The purified portion of the solder is then pumped back through a second heated pipe to the HASL solder pot. The solder reclaim system is an off-line system that operates continuously, without disrupting the operation of the HASL process.

One study found that approximately 96 percent of the solder was retained after skimming with a solder reclaim system, resulting in a remaining copper concentration of 0.16 percent, or a purification efficiency of better than 90 percent (Fellman, 1997). One PWB manufacturer reported a yearly decrease of 86 percent in solder consumption (see inset), decreasing their overall lead usage to below reportable levels (Sharp, 1999).

Solder Recovery Case Study of PWB Manufacturer

Before Solder Reclaim:
- 202,000 lbs solder usage/year
- 75,000 lbs lead usage reported

After Solder Reclaim:
- 27,000 lbs solder usage/year
- Lead usage below reportable level (less than 10,000 lbs)

Cost Comparison:
- Net cost of solder \$0.50/lb (\$2.10/lb solder - \$1.60/lb dross reclaim credit)
- Total solder usage reduction of 175,000 lbs/yr
- Total cost savings of \$82,000/yr
- Equipment cost is \$70,000
- Payback period is approximately one year

The average capital cost of a solder reclaim unit was reported to be $60,000 to $80,000. A cost analysis performed by one large PWB manufacturer found the expected payback period for this equipment to be one year, based upon an annual solder usage of 200,000 pounds per year, prior to the installation of the equipment.

Electrolytic Recovery

Electrolytic recovery, also known as electrowinning, is a common metal recovery technology employed by the PWB industry. Electrowinning uses an electrolytic cell to recover dissolved metal ions from solution. Operated either in continuous or batch mode, electrowinning can be applied to various process fluids including spent microetch, drag-out rinse water, and ion exchange regenerant. An advantage is its ability to recover only the metal from solution, leaving behind the other impurities that are present. The recovered metal can then be sold as scrap or traded for credit towards future bath chemistry. Electrowinning is typically used by PWB manufacturers to recover copper (effluent limit concerns) and gold (high price) from process baths or rinse tanks. It can also be used to recover other metals such as tin or silver, but this is not usually done because the metal does not exceed effluent treatment limits, or the recovery of the metal is not economically viable. Nickel recovery using electrowinning requires close control of pH; therefore, it is performed less frequently than for other metals, such as copper and gold (U.S. EPA, 1998).

The electrolytic cell is comprised of a set of electrodes (cathodes and anodes) placed in the metal-laden solution. An electric current, or voltage, is applied across the electrodes and through the solution. The positively charged metal ions are drawn to the negatively charged cathode where they deposit onto the surface. The solution is kept thoroughly mixed using air agitation or other proprietary techniques, to permit the use of higher current densities (the amount of current per surface area of cathode). These higher current densities shorten deposition time and improve the recovery efficiency. As the metal recovery continues, the concentration of metal ions in solution becomes depleted, requiring the current density to be reduced to maintain efficiency at an acceptable level. When the concentration of metal becomes too low for its removal to be economically feasible, the process is discontinued and the remaining solution is sent to final treatment.

Electrowinning is most efficient with concentrated solutions. Dilute solutions (less than 100 mg/l of metal) become uneconomical to treat due to the high power consumption relative to the amount of metal recovered (Coombs, 1993). Waste streams that are to be treated by electrowinning should be segregated, only combining streams containing the same metal, to prevent dilution, and to create a pure metal deposit free of other metal impurities. Already diluted solutions can be concentrated first, using ion exchange or evaporation techniques, to improve the efficiency and cost effectiveness of metal recovery.

Process waste solutions containing chlorine ions in any form should not be processed using electrolytic recovery methods, because the electrolysis of these solutions could generate chlorine gas. Solutions containing copper chloride salts should first be converted to non-chloride copper salt (e.g., copper sulfate) solutions, using ion exchange methods, before undergoing electrowinning to recover the copper content (Coombs, 1993).

The recovered metal(s) can be sold as scrap to a metals reclaimer. Typical metal removal efficiencies of 90 to 95 percent have been achieved using electrolytic methods (U.S. EPA, 1990). The remaining effluent will still contain small amounts of metal and will be acidic in nature (i.e., low pH). Adjusting the pH may not be sufficient for the effluent to meet the standards of some POTW authorities; therefore, further treatment may be required.

Eighteen percent of the Pollution Prevention Survey respondents reported using electrowinning as a resource recovery technology, with 89 percent of those being satisfied with its performance. The median cost of an electrowinning unit reported by the respondents was $15,000; however, electrowinning capital costs are dependent on the capacity of the unit.

Ion Exchange

Ion exchange is a process used by the PWB industry mainly to recover metal ions, such as copper, tin, or palladium, from rinse waters and other solutions. This process uses an exchange resin to remove the metal from solution and concentrate it on the surface of the resin. It is particularly suited to treating dilute solutions, since at lower concentrations the resin can process a greater volume of wastewater before becoming saturated. As a result, the relative economics of the process improve as the concentration of the feed solution decreases. Aside from recovering metals such as copper and silver, ion exchange also can be used for treating wastewater, deionizing feed water, and recovering chemical solutions.

Ion exchange relies on special resins, either cationic or anionic, to remove the desired chemical species from solution. Cation exchange resins are used to remove positively charged ions such as copper, tin, or other metals. When a feed stream containing a metal is passed through a bed of cation exchange resin, the resin removes the metal ions from the stream, replacing them with hydrogen ions from the resin. For example, if a feed stream containing copper sulfate ($CuSO_4$) is passed through the ion exchange resin, the copper ions are removed and replaced by hydrogen ions to form sulfuric acid (H_2SO_4). The remaining water effluent is either further processed using an anion exchange resin and then recirculated into the rinse water system, or pH neutralized and then directly sewered. Ion exchange continues until the exchange resin becomes saturated with metal ions and must be regenerated.

Special chelating resins have been designed to capture specific metal ions that are in the presence of chelating agents, such as metal ions in electroless plating baths. These resins are effective in breaking down the chemical complexes formed by chelators that keep metal ions dissolved in solution, allowing them to be captured by the resin. Hard water ions, such as calcium and magnesium, are not captured, creating a purer concentrate. Chelating resins require that the feed stream be pH-adjusted to reduce acidity, and filtered to remove suspended solids that will foul the exchange bed (Coombs, 1993).

Regeneration of the cation or chelating exchange resin is accomplished using a moderately concentrated (e.g., ten percent) solution of a strong acid, such as sulfuric acid. Regeneration reverses the ion exchange process by stripping the metal ions from the exchange resin and replacing them with hydrogen ions from the acid. The concentration of metal ions in the remaining regenerant depends on the concentration of the acid used, but typically ranges from
10 to 40 g/l or more (Coombs, 1993).

Ion exchange can be combined with electrowinning to recover metal from solutions that would not be cost effective to recover using either technology alone. A typical flow diagram for this type of system is shown in Figure 6-2. It can be used to concentrate a dilute solution of metal ions for electrolytic recovery that would otherwise be uneconomical to recover. For example, a dilute copper chloride solution can be treated by an ion exchange unit that is regenerated using sulfuric acid, producing a concentrated copper sulfate solution. The electrowinning unit can then be used to recover the copper from the solution while regenerating the acid, which could then be used for the next regeneration cycle. The recovery of gold from the drag-out and rinse tanks, following the immersion gold bath, is another example of where this configuration is typically used. The high cost of gold makes this system cost effective over the long term.

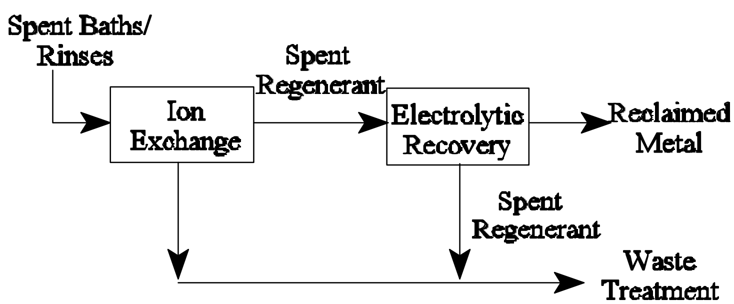

Figure 6-2. Flow Diagram of Combination Ion Exchange and Electrowinning Recovery System for Metal Recovery

A benefit of ion exchange is the ability to control the type of metallic salt that will be formed by selecting the type of acid used to regenerate the resin. In the previous example, the copper chloride was converted to copper sulfate while being concentrated by the ion exchange system. This is particularly useful when electrowinning is used, because it cannot process solutions containing the chlorine ion without usually generating toxic chlorine gas.

Forty-four percent of the respondents to the Pollution Prevention Survey reported using an ion exchange process as a water recycle/chemical recovery technology. Of these facilities, 90 percent indicated that they were satisfied with its overall performance. The average capital cost of a unit, which is related to its capacity, was reported to be $65,000 (with a low of $10,000 and a high of $120,000).

Reverse Osmosis

Reverse osmosis (RO) is a recovery process used by the PWB industry to regenerate rinse waters and to reclaim process bath drag-out for return to the process (U.S. EPA, 1990). It relies on a semi-permeable membrane to separate the water from metal impurities, allowing bath solutions to be reused. It can be used as a recycling or recovery technology to reclaim or regenerate a specific solution, or it can be part of an overall waste treatment process to concentrate metals and impurities before final treatment.

The semi-permeable membrane permits only certain components to pass through, and pressure is used as a driving force to separate the components at a useful rate. The membrane is usually made of a polymer compound (e.g., nylon) with hole sizes ranging from 0.0004 to 0.06 microns in diameter. Pumping of the waste stream, at pressures typically ranging from 300 to 1,500 pounds per square inch (psi) force the solution through the membrane (Capsule Environmental Engineering, Inc., 1993). The membrane allows the water to pass while inhibiting the metal ions, collecting them on the membrane surface. The concentrated metal ions are allowed to flow out of the system, where they are reused as bath make-up solution, or they are sent to treatment. The relatively pure water can be recycled as rinse water or directly sewered (sent to a POTW).

A typical RO system for recycling rinse water is shown in Figure 6-3. The effluent from rinse water tanks throughout the facility is collected in a conditioning tank. Any pretreatment that may be required, such as pH adjustment, takes place in the conditioning tank. The conditioning tank also acts to smooth out any chemical concentration spikes that may occur in the rinse effluent. The water is then passed through the RO membrane, where the metals and other dissolved solids are removed. The purified water is then passed on to a storage tank to be used for further rinsing operations, where required. The removed solids and other materials are sent to the wastewater treatment system to be processed. An RO system of this design will have an efficiency of 70 to 85 percent, with the remainder being sent to waste treatment (Hosea, 1998).

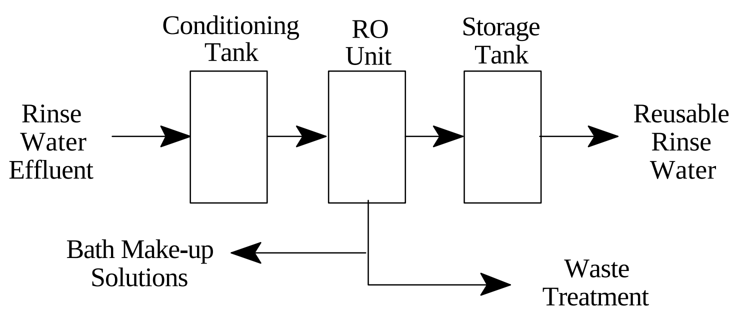

Figure 6-3. Reverse Osmosis Water Reuse System

The RO process has some limitations. The types of waste streams suitable for processing are limited by the ability of the polymeric membranes to withstand the destructive nature of the given waste stream. The membranes are sensitive to solutions with extreme pH values, either low or high, which can degrade them. Pure organic streams likewise are not treatable. Waste streams with suspended solids should be filtered prior to separation to keep the solids from fouling the membrane, to avoid reducing the efficiency of the process. Process membranes also may have a limited life due to the long-term pressure of the solution on the membrane (Coombs, 1993). Data regarding the usage of RO technology by the PWB industry were not collected in the Pollution Prevention Survey.

Off-Site Refining/Reclamation

Many of the surface finishing technologies are based on the deposition of precious metals. Due to the high cost of replacement, these baths are typically recharged rather than discarded, replacing the metal that has been plated to maintain proper operating concentrations. Should the baths become too contaminated to operate properly, the baths are replaced with new chemistry and the spent bath solution is sent to a chemical refinery to reclaim the value of the remaining precious metal content. The most likely solutions to be refined to recover their value are those containing gold and palladium. The value of the recovered metal is based on the current spot market price of the metal. Table 6-6 lists the current value of the metal and the typical methods of recovery.

Table 6-6. Typical Value of Reclaimed Metals (1999) and Recovery Methods

Metal	Price [a,b]	Recovery Method [c]
Gold	$283/oz	Off-site refining or electrolytic
Palladium	$636/oz	Off-site refining
Silver	$4.98/oz	Off-site refining or ion exchange
Copper	$0.80/lb	On-site electrolytic or ion exchange
Solder	$1.60/lb	Manual or solder recovery system

[a] Metal prices received will be current market prices minus a 2 to 5 percent refining fee. Prices listed are spot prices on 7/6/00 obtained from www.kitco.com.
[b] Solder cost obtained from Alpha Metals (03/00). Copper price reflects London metal exchange price on 7/6/00 obtained from www.nickelalloy.com.
[c] Methods of recovery are typical methods and do not represent all recovery options.

Some chemical suppliers provide this service to their customers, accepting spent bath solution in exchange for credit toward future chemical purchases. While the fee charged to recover the metal from the bath is similar to that charged by a refinery service (2 to 5 percent), PWB manufacturers may find it easier to deal with a single company to both supply bath chemicals and to reclaim the spent bath solution, rather than contracting with a separate waste recovery service (Schectman, 1999).

The chemical supplier also benefits from providing this service, because the companies that receive credit are more likely to continue purchasing their chemical products. Chemical suppliers also may be able to reuse the spent solution, regenerating the stock into new bath solution, rather than treating and discarding the remaining solution.

Both gold and palladium plating baths are routinely refined to recover the value of the remaining metal. The value of the metals combined with the high concentration of metal ions remaining, even in a spent bath, makes refining worthwhile. Silver plating baths do not typically have sufficiently high concentrations of silver ions to warrant refining for economic reasons. However, in some instances, silver baths may be combined with other silver-bearing waste streams, such as photo developing solutions, before being refined, making it more cost effective to recover the metal (Sharp, 1999).

Although the low recovery value of copper, tin, and nickel prevent refining from being economically advantageous, these solutions are at times sent off-site to a reclaimer, at a cost to the PWB manufacturer, because the facility lacks the capability to treat the solution or does not want to deal with the extra treatment steps and risks involved. The value of the metal recovered from the solution is credited to the PWB manufacturer, but is usually insufficient to cover the entire expense of the refining and disposal (Schectman, 1999). These metals, particularly copper, also can be recovered on-site using ion exchange or electrowinning, when the recovered metal can be sold to a reclaimer to partially offset the cost of recovery.

Applicability of Recovery Technologies

Recovery and reclamation technologies typically are quite efficient, but are designed for a specific application, which is usually chemical-specific in nature (e.g., electrowinning removes positively charged metal ions), often limiting their applicability. Because surface finishing processes are comprised of a series of chemical baths of different chemical characteristics, it is appropriate to match the recovery technologies with individual chemical baths when identifying opportunities for recycling or reclaiming materials. Table 6-7 displays the applicability of the various recycling and recovery technologies to each of the surface finishing chemical baths. Bath types that do not require additional recycling, are not economically feasible to recycle, or those for which a recycling technology does not exist are not listed in the table. Recovery technologies can sometimes be combined (e.g., ion exchange followed by electrowinning to recover metal) into a more cost effective recovery system that achieves greater removal efficiency.

Table 6-7. Applicability of Recovery/Reclamation Technologies by Bath Type

Bath Type	Process(es)	Solder Recovery	Ion Exchange	Electrolytic Recovery	Reverse Osmosis	Off-Site Refining
Drag-out Rinse (following gold, palladium)	Nickel/Gold and Nickel/Palladium/Gold		X	X		X
Gold	Nickel/Palladium/Gold		X	X		X
Microetch	All		X	X		
Nickel	Nickel/Gold and Nickel/Palladium/Gold		X	X		
Palladium	Nickel/Palladium/Gold					X
Immersion Silver	Immersion Silver		X	X		X
Solder	HASL	X				
Immersion Tin	Immersion Tin		X	X		
Water Rinse	All				X	

6.2.2 Control Technologies

If the release of a hazardous material cannot be prevented or recycled, it may be possible to treat or reduce the impact of the release using a control technology. Control technologies are engineering methods that minimize the toxicity and/or volume of released pollutants. Most of these methods involve altering either the physical or chemical characteristics of a waste stream to isolate, destroy, or alter the concentration of target chemicals. While this section focuses on technologies that are used to control on-site releases from a surface finishing process, many of these technologies are also applicable to other PWB process lines.

Control technologies are typically used to treat on-site releases to both water and air resulting from the application of a surface finish to the PWB. Wastewater containing concentrations of heavy metal ions, along with chelators and complexing agents, are of particular concern. Water effluent standards require the removal of most heavy metals and toxic organics from the plant effluent before it can be disposed to the sewer. On-site releases of concern to air include acid vapors and solvent fumes. This section identifies the control technologies used by PWB manufacturers to treat or control wastewater and air emissions released by the operation of the surface finishing processes.

Wastewater Treatment

The PWB industry typically uses a sophisticated treatment system to pretreat process wastewater and spent bath chemistries prior to discharge. The treatment system is comprised of several parts, including a versatile waste collection system, a flow-through precipitation process, a series of batch treatment tanks, and a sludge thickening process. The treatment also may be supplemented by other treatment technologies, depending on the treatment concerns for the facility and the effluent permit limits. Together these processes form a complete treatment system capable of treating the waste streams generated by the PWB manufacturing process, including those from the surface finishing line.

A diagram of a typical PWB facility treatment system is presented in Figure 6-4, while the individual treatment processes are discussed below. References to key points of the diagram are included in the descriptions, and are denoted with reference number in brackets.

Waste Collection and Segregation System. Waste streams are collected from processes located throughout the facility by a sophisticated piping and collection system that conducts the individual waste streams to the waste treatment process. The collection system must be versatile, allowing the waste treatment operators complete control over the destination of an incoming wastewater flow. In the case of a chemical spill or harmful accidental discharge, operators must have the ability to divert the wastewater flow into a holding tank to prevent any violations that might be caused by overloading the treatment system.

The treatment process typically has a waste collection tank and one or more holding tanks. The collection system deposits the individual waste streams into one or more collection tanks at the operator’s discretion. Waste streams are typically co-mingled in the main collection tank (1) for a period of time prior to entering the waste treatment system, to allow complete mixing and to smooth out any concentration spikes that might occur during normal process operation.

Difficult-to-treat streams, such as those containing chelators or requiring special treatment, are segregated from the others at the source and fed into separate holding tanks. Metal-bearing rinses should be segregated from streams which do not contain metals. Specific segregation of cyanide, solvents, flux, and reflow oils is critically important (Iraclidis, 1998). Waste streams containing oxidizing agents also typically are segregated from others because of the difficulty oxidizing agents present during the flocculation and settling stages (oxidizing agents evolve gas that can hinder floc settling) (Sharp, 1999).

Flow-Through Chemical Precipitation System. In the PWB industry, the majority of facilities surveyed (61 percent) reported using a conventional chemical precipitation system to accomplish the removal of heavy metal ions from wastewater. Chemical precipitation is a process for treating wastewater that depends on the water solubility of the various compounds formed during treatment. Heavy metal cations present in the wastewater are reacted with certain treatment chemicals to form hydroxides, sulfides, or carbonates that have relatively low water solubilities. The resulting heavy metal compounds are precipitated from the solution as an insoluble sludge that is subsequently sent off-site to reclaim the metals content, or sent to disposal. Chemical precipitation can be carried out in a batch process, but is typically operated in a continuous flow-through process to treat wastewater.

In the chemical precipitation treatment of wastewater from PWB manufacturing, the removal of heavy metals may be carried out by a unit sequence of rapid mix precipitation, flocculation, and clarification. The process begins by adjusting the pH of the incoming wastewater (2) to optimum operating conditions (pH 6 to 8). The optimum pH for treatment is dependant on both the treatment chemistry and the metals being removed from the wastewater. Adjustments are made through the addition of acid or lime/caustic. Treatment chemicals are then dispersed into the wastewater input stream under rapid mixing conditions. The initial mixing unit (3) is designed to create a high intensity of turbulence in the reactor vessel, promoting multiple encounters between the metal ions and the treatment chemical species, which then react to form insoluble metal compounds. The type of chemical compounds formed depends on the treatment chemical employed; this is discussed in detail later in this section. These insoluble compounds form a fine precipitate at low pH levels and remain suspended in the wastewater.

The wastewater then enters the flocculation tank (4). The purpose of the flocculation step is to transform smaller precipitates into large particles that are heavy enough to be removed from the water by gravity settling in the clarification step. The flocculation tank uses slow mixing to promote collisions of precipitate particles suspended in the wastewater. The degree of flocculation is enhanced through the use of flocculating chemicals such as cationic or anionic polymers. These chemicals promote interparticle adhesion by adding charged particles to the wastewater, which attach themselves to the precipitate, thereby increasing the growth rate of the precipitate particles.

Wastewater effluent from the flocculation stage is then fed into a clarification tank (5) where the water is allowed to collect undisturbed. The rather large precipitate particles settle out of the water by gravity, forming a blanket of sludge at the bottom of the clarification tank. A portion of the sludge, typically 10 to 25 percent, is often recirculated to the head of the flocculation step to reduce chemical requirements, as well as to enhance the rate of precipitation (Frailey, 1996). The sludge particles provide additional precipitation nuclei that increase the probability of particle collisions, resulting in a more dense sludge deposit. The remaining 75 to 90 percent of the sludge from the clarifier is fed into the sludge-thickening tank.

The remaining supernatant from the clarifier is decanted through a weir into the bottom of a sand filter (6). As the water flows upward through the sand filter, the sand traps any remaining suspended solids, polishing the treated wastewater stream. When the sand filter becomes saturated with particles, and the effluent quality begins to deteriorate, the filter is taken off-line and back flushed to remove the particulate matter, cleansing the filter for further use. The collected particulate matter is sent to the sludge treatment system.

The treated wastewater then undergoes a final pH adjustment (7) to meet effluent guidelines and is then pumped into a final collection tank prior to being discharged. The collection tank allows for final testing of the water and also can act as a holding tank to capture any water that fails inspection due to a system overload of contaminant or some other treatment system failure. Water from this tank can be returned by the operator to the start of the process if required.

Other process steps are sometimes employed in the case of unusually strict effluent limits. Filtration, reverse osmosis, ion exchange, or additional precipitation steps are sometimes employed to further reduce the concentration of chemical contaminants present in the wastewater effluent.

Batch Treatment of Process Baths. Most spent process baths can be mixed with other wastewater and treated by the on-site wastewater treatment process using chemical precipitation. Chemical suppliers, however, recommend that some process baths be treated separately from the usual waste treatment process. The separate treatment of these baths is usually recommended due to the presence of strong chelating agents, high metal concentrations or other chemicals, such as additives or brighteners, which require additional treatment measures before they can be disposed of properly. Spent bath solution requiring special treatment measures can be processed immediately, but is typically collected and stored until enough has accumulated to warrant treatment. Batch treatment (8) of the accumulated waste is then performed in a single tank or drum, following the specific treatment procedures provided by the chemical supplier for that bath.

Following batch treatment, the remaining solution may be transferred to the flow-through precipitation system for further treatment, drummed for disposal, or discharged directly. Sludge from the process is dewatered by a sludge press and then combined with other treatment sludge to be dried.

Sludge Thickening Process. Sludge formed in the clarifier needs to be thickened and dewatered prior to being shipped off-site. Clarifier sludge is typically light (4 to 5 percent solids) and not very well settled prior to entering the thickening tank (9). Once in the tank, the precipitate is compressed as it moves downward by the weight of the precipitate above and by the constricting funnel at the bottom of the thickening tank. The supernatant separates from the sludge as it thickens. It is pumped from the top of the thickener and returned to the wastewater collection tank to be processed through the treatment system once again. The dense, thickened sludge (8 to 10 percent solids) is then pumped from the bottom of the thickening tank to a sludge press.

The sludge press (10) and sludge dryer (11) minimize the volume of sludge by increasing the solids content through dewatering, thus reducing the cost of disposal. The sludge press is usually a plate filter press, but belt filter presses also may be used. Dewatering occurs when the sludge is passed under high pressure through a series of cloth covered plates. The cloth quickly becomes coated with sludge, forming a layer that retains the solids, while the water is forced through the cloth. The sludge cake (30 to 35 percent solids) is sufficiently dry for direct disposal or recovery (Pontius, 1990). A sludge dryer (up to 70 percent solids) may be utilized to further dewater the sludge, if desired.

Treatment of Non-Chelated Wastewater. The absence of complexing chemicals (e.g., ammonia) or chelating agents (e.g., EDTA) in the wastewater stream simplifies the removal of metal ions by precipitation. Metal removal from such waste streams is accomplished through simple pH adjustment using hydroxide precipitation. Caustic soda is typically used while other treatment chemicals include calcium hydroxide and magnesium hydroxide. The heavy metal ions react with the caustic soda to form insoluble metal hydroxide compounds that precipitate out of solution at a high pH level. After the precipitate is removed by gravity settling, the effluent is pH adjusted to a pH of seven to nine and then sewered. The treatment can be performed in a chemical precipitation process similar to the one shown in Figure 6-4, resulting in a sludge contaminated with metals that is then sent to recycling or disposal.

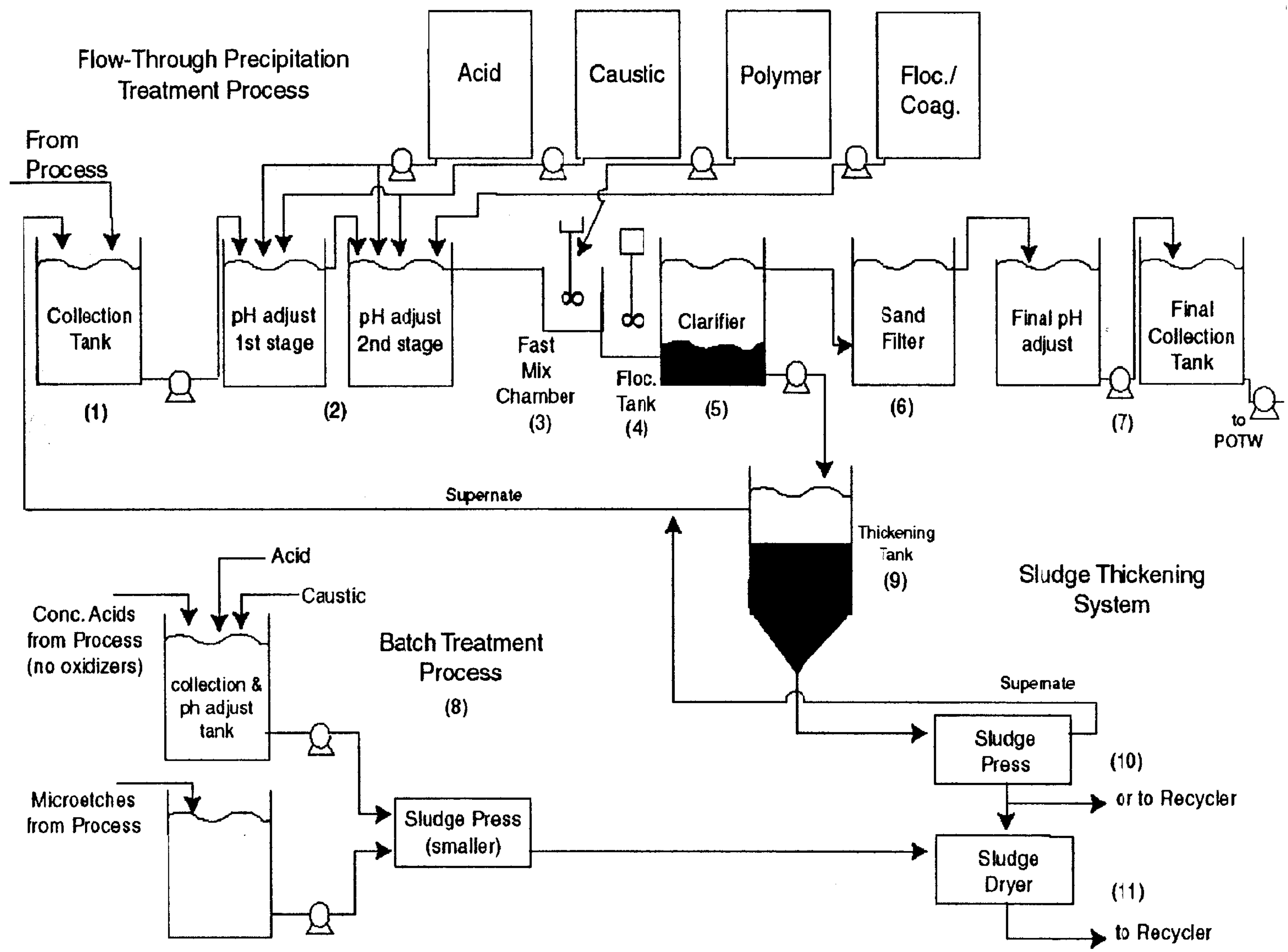

Figure 6-4. Typical PWB Waste Treatment System

Treatment of Wastewater Containing Chelated Metals. The presence of complexing chemicals or chelators, such as EDTA, formaldehyde, thiourea, and quadrol require a more vigorous effort to achieve a sufficient level of metal removal. Chelators are chemical compounds that inhibit precipitation by forming chemical complexes with the metals, allowing them to remain in solution beyond their normal solubility limits. These chemicals are found in spent surface finishing plating baths, in cleaners, and in the water effluent from the rinse tanks following these baths. Treatment chemicals enhance the removal of chelated metals from water by breaking the chelate-to-metal bond, destroying the soluble complex. The freed metal ions then react to form insoluble metal compounds, such as metal hydroxides, that precipitate out of solution.

Several different chemicals are currently being used to effectively treat chelator contaminated wastewater resulting from the manufacture of PWBs. Some common chemicals used in the treatment of wastewater produced by the surface finishing process are briefly described in Table 6-8. For more information regarding individual treatment chemicals and their applicability to treating specific wastes, consult a supplier of waste treatment chemicals.

Chelated waste streams are typically segregated from non-chelated streams to minimize the consumption of expensive treatment chemicals. Treatment of small volumes of these waste streams is typically done in a batch treatment tank. A facility with large volumes of chelated waste often will have a separate, dedicated flow-through chelated precipitation system to remove the chelated metals from the wastewater.

Alternative Treatment Processes. Although chemical precipitation (61 percent of those surveyed) is the most common process for treating wastewater used by PWB manufacturers, other treatment processes exist. Survey respondents reported the use of ion exchange (30 percent) to successfully treat wastewater generated from the manufacture of PWBs. Thirty-six percent of the ion exchange systems also combined with electrowinning to enhance treatment. These processes operate separately or in combination to efficiently remove metal ions from chelated or non-chelated waste streams, typically yielding a highly concentrated sludge for disposal. These processes were discussed in Section 6.2.1.

Despite the supplier's recommendations, PWB facilities sometimes treat individual process baths using their typical wastewater treatment process. Spent bath solutions can be mixed slowly, in small quantities, with other wastewater before being treated, thus diluting the concentration of the chemical species requiring treatment. However, the introduction of concentrated wastes to the wastewater could result in increased treatment chemical consumption and more sludge produced than if batch treated separately. Also, the introduction of a chemical species not typically found in the wastewater may adversely affect the treatment process or require more vigorous treatment chemicals or processes. Factors affecting the success of this approach include the type of treatment chemicals used, the contaminant concentrations in the wastewater, and the overall robustness of the existing, in-house treatment process.

Table 6-8. Treatment Chemicals Used to Remove Metals From Chelated Wastewater

Chemical	Description
Ferrous Sulfate	Inexpensive treatment that requires iron concentrations in excess of 8:1 of copper and other metals to form an insoluble metal hydroxide precipitate (Coombs, 1993). Ferrous sulfate is first used as a reducing agent to break down the complexed copper structures under acidic conditions before forming the metal hydroxide during subsequent pH neutralization. Drawbacks include the large volumes of sludge generated and the presence of iron which reduces the value of sludge to a reclaimer.
DTC (Dimethyl-dithiocarbamate)	Moderately expensive chemical that acts as a complexing agent, exerting a stronger reaction to the metal ion than the chelating agent, effectively forming an insoluble heavy metal complex. The sludge produced is light in density and difficult to separate by gravity (Guess, 1992; Frailey, 1996).
Sodium Sulfide	Forms metal sulfides with extremely low solubilities that precipitate even in the presence of chelators. Produces large volume of sludge that is slimy and difficult to dewater (Guess, 1992).
Polyelectrolyte	Polymers that remove metals effectively without contributing to the volume of sludge. Primary drawback is the high chemical cost (Frailey, 1996).
Sodium Borohydride	Strong reducing agent reduces metal ions, then precipitate out of solution forming a dense, low volume sludge. Drawbacks include its high chemical cost and the evolution of potentially explosive hydrogen gas (Guess, 1992; Frailey, 1996).
Ferrous Dithionite	Reduces metal ions under acidic conditions to form metallic particles that are recovered by gravity separation. Excess iron is regenerated instead of being precipitated, producing a low volume sludge (Guess, 1992).
TMT 15 (Tri-mercaptotriazine)	Designed specifically to precipitate silver ions, which are unaffected by other treatment chemicals, from wastewater. Primary drawbacks are the high chemical to silver removed weight ratio and the high chemical cost (Sharp, 1999).

Individual Alternative Treatment Profiles

There are often many approaches from which a facility can choose to properly treat and dispose of a process waste stream. Several of the approaches, which have been discussed in this CTSA chapter, include reclamation, recycling, treatment, disposal, or a combination of these. The treatment or recycling method used by a facility for each waste stream is dependent on a number of factors including discharge permit effluent limits (is more vigorous treatment required to meet effluent limits?), economics (is the treatment cost effective?), the capability of on-site treatment system (e.g., the presence of reclamation technologies), the treatment requirements of processes other than the surface finishing line (e.g., can the waste stream be combined with other waste streams to make other treatment options more applicable), and a facility’s preference, based on experience. One, or a combination of several of these factors, will dictate the treatment options available to a particular facility.

Chemical suppliers offer guidance on the proper treatment and disposal of their process chemicals and are available to consult with facilities investigating treatment options. Process baths often contain proprietary ingredients that are known only to the chemical manufacturer. These may impact the manner in which the bath can be successfully treated. Prior to deciding on a treatment method for a particular bath, a PWB manufacturer should consult with the chemical supplier to confirm the applicability of the method and to identify any problems or concerns that may arise.

A profile for treating PWB surface finishing chemical baths is given in Table 6-9. The profile was developed and reviewed by PWB manufacturers participating in this project as an example of the treatment requirements of the individual chemical baths. Treatment of similar baths by individual facilities may differ from that presented in Table 6-9, according to the requirements/preferences of each facility.

Batch treatment is indicated for bath types containing chemicals or metals that require special treatment considerations beyond that provided by the precipitation system. Batch treatment could be required due to the presence of chelating agents, oxidizers, pH concerns, chemical constituents not affected by precipitation (e.g., organic compounds, silver which is unaffected by typical treatment chemicals, etc.), or to minimize the use of expensive treatment chemicals. After batch treatment, the remaining supernatant may be fed through the precipitation system for additional treatment, if required, drummed and sent out, or disposed directly to the POTW, if it meets the effluent limits of the facility.

The batch treatment of microetches is typically done separately from other process wastes due to the presence of chemical oxidizers in the microetch baths. Oxidizers commonly found in PWB waste streams include nitric acid, peroxides, persulfates, and permanganates. These compounds evolve gas during the treatment process, which hinders floc settling and, thereby, reduces the overall efficiency of the treatment process. Waste streams containing oxidizers can often be combined during treatment.

Metal reclamation is indicated for baths with metal concentrations that might typically exceed effluent limits, or that are too valuable to simply discard. Metals reclamation can be performed on-site using one, or a combination of metal recovery technologies, or can be sent off-site to a metal refiner.

Table 6-9. Treatment Profile of PWB Surface Finishing Process Baths

Bath Type	Process(es)	Chelated	Typical Treatment Method [a]
Acid Dip	Nickel/Gold and Nickel /Palladium/Gold	N	Batch treatment - no oxidizers.
Catalyst	Nickel/Gold and Nickel /Palladium/Gold	N	Metals reclamation on-site or off-site.
Cleaner	All	Y	Batch treatment - no oxidizers.
Drag-out Rinse (following gold, palladium)	Nickel/Gold and Nickel /Palladium/Gold	Y	Metals reclamation on-site or off-site.
Electroless Gold	Nickel/Gold and Nickel /Palladium/Gold	Y	Metals reclamation on-site or off-site.
Electroless Nickel	Nickel/Gold and Nickel /Palladium/Gold	Y	Batch treatment - no oxidizers for chelated waste streams.
Electroless Palladium	Nickel/Gold and Nickel /Palladium/Gold	Y	Metals reclamation on-site or off-site.
Flux	HASL	N	Hazardous waste disposal.
Immersion Silver	Immersion Silver	Y	Point of generation treatment equipment (e.g., ion exchange, iron exchange, etc.) to remove silver, then to batch treatment - no oxidizers for chelated streams.
Immersion Tin	Immersion Tin	Y	Batch treatment for the destruction of thiourea followed by precipitation treatment to remove the remaining tin.
Microetch	All	N	Batch treatment - oxidizers only.
OSP	OSP	N	Batch treatment - no oxidizers.
Predip	Immersion Tin and Immersion Silver	N	Batch treatment - no oxidizers.
Solder/Dross	HASL	N	Metals reclamation off-site.
Water Rinse	All	N	Flow-through precipitation system.

Source: Sharp, 1999.

[a] Treatment methods represent the typical method by which the bath is treated. Indicated method is not the only way a bath may be treated by an individual facility. Typical methods were developed and reviewed by PWB manufacturer project participants.

Air Pollution Control Technologies

Air pollution control technologies are often used by the PWB industry to cleanse air exhaust streams of harmful fumes and vapors. Exactly half (50 percent) of the PWB facilities surveyed have installed air scrubbers to control air emissions from various manufacturing processes, and almost a quarter of the facilities (23 percent) scrub air releases from surface finishing processes. The first step of any air control process is the effective containment of fugitive air emissions at their source of release. This is accomplished using fume hoods over the process areas from which the air release of concern occurs. These hoods may be designed to continuously collect air emissions for treatment by one of the methods described below.

Gas Absorption. One method for removing pollutants from an exhaust stream is by gas absorption in a technique sometimes referred to as air scrubbing. Gas absorption is defined as the transfer of material from a gas to a contacting liquid or solvent. The pollutant is chemically absorbed and dispersed into the solvent, leaving the air free of the pollutant. The selection of an appropriate solvent should be based on the liquid's solubility for the solute, and the cost of the liquid. Water is used for the absorption of water-soluble gases, while alkaline solutions are typically used for the absorption of acid gases. Air scrubbers are used by the PWB industry to treat wet process air emissions, such as formaldehyde and acid fumes, and emissions from other processes other than the surface finishing process.

Gas absorption is typically carried out in a packed gas absorption tower, or scrubber. The gas stream enters the bottom of the tower and passes upward through a wetted bed of packing material before exiting the top. The absorbing liquid enters the top of the tower and flows downward through the packing before exiting at the bottom. Absorption of the air pollutants occurs during the period of contact between the gas and liquid. The gas is either physically or chemically absorbed and dispersed into the liquid. The liquid waste stream then is sent to water treatment before being discharged to the sewer. Although the most common method for gas absorption is the packed tower, other methods exist such as plate towers, sparged towers, spray chambers, or venturi scrubbers (Cooper and Alley, 1990).

Gas Adsorption. The removal of low concentration organic gases and vapors from an exhaust stream can be achieved by the process of gas adsorption. Adsorption is the process in which gas molecules are retained on the interface surfaces of a solid adsorbent by either physical or chemical forces. Activated carbon is the most common adsorbent, but zeolites, such as alumina and silica, are also used. Adsorption is used primarily to remove volatile, organic compounds from air, but is also used in other applications such as odor control and drying process gas streams (Cooper and Alley, 1990). In a surface finishing process, gas adsorption can be used to recover volatile organic compounds, such as formaldehyde.

Gas adsorption occurs when the vapor-laden air is collected and then passed through a bed of activated carbon or another adsorbent material. The gas molecules are adsorbed onto the surface of the material, while the clean, vapor-free air is exhausted from the system. The adsorbent material eventually becomes saturated with organic material and must be replaced or regenerated. Adsorbent canisters, which are replaced on a regular basis, are typically used to treat small gas flow streams. Larger flows of organic pollutants require packed beds of adsorbent material, which must be regenerated when the adsorbent becomes saturated (Cooper and Alley, 1990).

Regeneration of the adsorbent is typically accomplished by a steam-stripping process. The adsorbent is contacted with low-pressure steam which desorbs the adsorbed gas molecules from the surface of the packed bed. Following condensation of the steam, the organic material is recovered from the water by either decanting or distillation (Campbell and Glenn, 1990).

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